What is the effect of the (stratospheric) residual circulation on lower stratospheric static stability and tropopause structure?
Background

- Stratospheric residual (~ Brewer-Dobson) circulation tends to: lift tropical tropopause and lower extratropical tropopause
  → By how much?
- Lower stratospheric static stability exhibits characteristic vertical structure (~ tropopause inversion layer, TIL)
  → To what extent is this structure related to the residual circulation?
Thuburn & Craig (2000)

Stratospheric momentum forcing

Tropopause height (km)

Latitude

strong circulation

weak circulation

control run
From Vallis (2006)
downwelling
tropospheric circulation
Tools

- Canadian Middle Atmosphere Model (CMAM): comprehensive CCM, T47L71, i.e. vertical resolution near tropopause ~ 1 km
- ERA40 on model levels (T159L60), vertical resolution similar to CMAM near tropopause
- Only CMAM results will be shown here, but all results are consistent between CMAM and ERA40.
→ enhanced $N^2$ just above the (global) tropopause
→ tropopause inversion layer (TIL)

→ note vertical structure of residual circulation near the tropopause
Transformed Eulerian (∼ Residual) Mean Thermodynamic Equation

\[ \partial_t \bar{\Theta} + \bar{w}^* \partial_z \bar{\Theta} + \bar{u}^* \partial_y \bar{\Theta} \approx \bar{Q} \]

Residual Vertical & Meridional Velocities

Diabatic Heating (mainly radiative in the stratosphere)

form equation for \( \bar{N}^2 = g \bar{\Theta}^{-1} \partial_z \bar{\Theta} \):

\[ \partial_t \bar{N}^2 \approx -\partial_z (\bar{w}^* \bar{N}^2) - g \partial_z (\bar{u}^* \bar{\Theta}^{-1} \partial_y \bar{\Theta}) + g \partial_z (\bar{\Theta}^{-1} \bar{Q}) \]

Vertical structures of both, \( w^* \) and \( N^2 \) are important!

usually small
Forcing due to Residual Circulation

\[ \Theta - \text{Heating Rates (K/day)} \]

\[ -\bar{u}^* \partial_y \bar{\Theta} - \bar{w}^* \partial_z \bar{\Theta} \]

\[ \text{Static Stability Forcing (10}^{-5}\text{s}^{-2}/\text{day)} \]

\[ -\partial_z (\bar{w}^* \bar{N}^2) - g \partial_z (\bar{v}^* \bar{\Theta}^{-1} \partial_y \bar{\Theta}) \]

- dark/light shading: values above/below ±0.4 K/day (left), above/below ±0.3 \cdot 10^{-5}s^{-2}/day (right)
- dominant contribution (with few exceptions) comes from vertical residual velocity contribution
Forcing due to Residual Circulation

\[ -\overline{u^*} \partial_y \Theta - \overline{w^*} \partial_z \Theta \]

\( \Theta \) - Heating Rates (K/day), DJF

Tropical Upwelling

Extratropical Downwelling

Localized subtropical upper tropospheric warming maximum

double tropopause formation?

(slight) cooling @ subtropical edges of tropical TP is due to meridional contribution!

Note vertical structure near tropopause!
Forcing due to Residual Circulation

\[-\partial_z (\overline{w^* N^2}) - g \partial_z (\overline{v^* \Theta^{-1}} \partial_y \Theta)\]

Static Stability Forcing (10^-5 s^-2/day), DJF

Large negative forcing in subtropical uppermost troposphere
(combined effect of vertical and meridional contribution)
double tropopause formation?

Dipole structure of positive forcing just above TP (due to $\overline{w^*}$) and negative forcing just below TP (due to $\overline{v^*}$)

pronounced forcing structure everywhere around the tropopause
Stratospheric Radiative Equilibrium (SRE) Solutions:
• constrain tropospheric climate to the one simulated by CMAM
• perform off-line radiative transfer calculations (clear-sky, using CRM) to obtain stratospheric temperatures in radiative equilibrium given CMAM's tracer distribution

Stratospheric Circulation-Radiation (SCR) Solutions:
• add circulation-induced heating rates to above radiative calculations

How do the resulting tropopause height and lower stratospheric static stability compare to CMAM?
Stratospheric Radiative Equilibrium Temperature Perturbation $T_{rad} - T_{CMAM}$

→ expected warm/cold dipole structure between tropics and extratropics
→ much lower tropical tropopause in SRE ($\sim 3$–$4$ km), somewhat higher extratropical tropopause ($\sim 1$–$2$ km)
Stratospheric Radiative Equilibrium Static Stability ($N^2$) Structure

→ note strongly reduced $N^2$ in winter polar regions due to polar night (no strat. dynamical heating)
→ tropical TIL weakened compared to CMAM
→ note good agreement between circulation-radiation tropopause (dotted) and CMAM's tropopause (full)
→ much stronger tropical TIL than in SRE solution
Conclusions

- Stratospheric residual (Brewer-Dobson) circulation strongly enhances equator-to-pole contrast in tropopause height (by ~ factor of 2 compared to a stratosphere in radiative equilibrium)

- Dipole structure of strongly positive (negative) static stability forcing just above (below) the mid-latitudinal tropopause in winter effectively sharpens tropopause and appears to cause TIL there

- Forcing structure in subtropical upper troposphere should favor formation of double tropopauses